NUWC-NPT Technical Document 11,737
1 March 2006

Chirp Shock Test Machine: A Laboratory-Based Shock Test Tool

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NAVSEA WARFARE CENTERS
NEWPORT

Naval Undersea Warfare Center Division
Newport, Rhode Island

PREFACE

This technical document was funded under NUWC Division Newport Project No. CSO155, "Chirp," principal investigator Peter Estrela (Code 252). The sponsoring activity is the Naval Sea Systems Command, program manager Vincent Calhoun (PMS 350).

The authors gratefully acknowledge the unwavering support of Vincent Calhoun, Michael Stiller (PMS 394), and Joseph Rhine (PMS 425).

Reviewed and Approved: 1 March 2006

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
1 March 2006

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
Chirp Shock Test Machine: A Laboratory-Based Shock Test Tool

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Undersea Warfare Center Division
1176 Howell Street
Newport, RI 02841-1708

8. PERFORMING ORGANIZATION REPORT NUMBER
TD 11,737

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Naval Sea Systems Command (PEO-SUB)
614 Sicard ST SE Stop 7004
Washington Navy Yard DC 20376-7004

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This document describes the Chirp Shock Test Machine and demonstrates that this shock test tool has the potential to enhance the Navy's current shock-test program. The operational effectiveness of the Fleet would be improved while at the same time significant savings in personnel and equipment costs for shock testing and verification would be realized.

14. SUBJECT TERMS
Shock Testing of Submarine Equipment Commercial-off-the Shelf Equipment Shock Testing
Grade-A Equipment Verification MIL-S-901D I.C. #1 Floating Shock Platform
Chirp Shock Test Machine Laboratory-Based Shock Testing

15. NUMBER OF PAGES
25

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

EXECUTIVE SUMMARY

Because of increased budgetary constraints, the U.S. Navy continues to emphasize the use of commercial off-the-shelf (COTS) equipment to meet its unique shipboard requirements. This trend has introduced a new set of problems and concerns. For example, the rapid advances in technology result in constant changes in COTS hardware and software, forcing the Navy to continually update shipboard equipment or face obsolescence and the inability to adequately support the systems in the Fleet. Verifying that equipment—particularly COTS equipment, which is inherently less hardened than militarized equipment—can withstand combat-induced shock loads is more critical than ever, especially for those components that are vital to a ship's safety and self-protection capability (that is, Grade A equipment).

Traditional shock testing methods, particularly those for shock-isolated COTS equipment, are often very expensive and time consuming. The resultant impact on a program's funding and/or schedule frequently forces reliance on methods other than actual testing (for example, analysis, extensions, and waivers). These compromises only serve to degrade a ship's ability to continue functioning in a wartime environment.

The Navy needs new, innovative approaches to verifying equipment's ability to withstand extreme environmental stresses. This need is especially relevant to the issue of shock testing. The Chirp Shock Test Machine—which is the only Navy laboratory-based machine capable of performing controlled, low-frequency, large-displacement testing of shock-isolated equipment and components or equipment to be installed on isolated decks—seamlessly affords one of these innovative approaches. The Chirp Machine provides the Navy with a shock test vehicle that is not only capable of being tailored to a specific ship's environment but is also repeatable in functionality for rapid retesting—both achieved with substantial cost and time savings.

The Chirp Shock Test Machine is not a replacement for traditional shock test methods (for example, the Floating Shock Platform); it is, however, an existing, but under-utilized, effective shock test tool that has particular relevance for today's Navy, which is increasingly resorting to COTS equipment for shipboard installation.

This document describes the Chirp Shock Test Machine to promote its increased use as a low-cost supplement (and, in some cases, alternative) to traditional shock testing.

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LIST OF ABBREVIATIONS AND ACRONYMS

C^3I	Command, control, communications, and intelligence
COTS	Commercial off-the-shelf
DOD	Department of Defense
DODD	Department of Defense directive
ECP	Engineering change proposal
EDM	Engineering design model
FSP	Floating Shock Platform
IEEE	Isolated electronic equipment enclosure
LMCO	Lockheed Martin Corporation
MWSM	Medium Weight Shock Machine
NSWC	Naval Surface Warfare Center
NUWC	Naval Undersea Warfare Center
SABP	Sphere array beamformer processor
SRS	Shock response spectrum
TEC	Tomahawk equipment cabinet
TTWCS	Tactical Tomahawk Weapon Control System

CHIRP SHOCK TEST MACHINE: A LABORATORY-BASED SHOCK TEST TOOL

1. INTRODUCTION

In the early 1990s, the Naval Sea Systems Command (NAVSEA) tasked the Naval Undersea Warfare Center (NUWC) Detachment, New London, CT, with the conceptual design and analysis of a variable-frequency (3 to 12 Hz) shock machine. The end result of this task was the fabrication of the Chirp Shock Test Machine—the only Navy laboratory-based machine capable of performing controlled, low-frequency, large-displacement testing of shock-isolated equipment and components or equipment to be installed on isolated decks (see reference 1).

The Chirp Shock Test Machine is ideally suited for replicating the low-frequency, large-displacement shock environment that is typically experienced by components, principal units or cabinets, and decks that are shock-isolated. The Chirp Machine has been utilized in the shock testing of diverse pieces of equipment:

- An isolated electronic equipment enclosure (IEEE) prototype cabinet;
- Two components of the Tactical Tomahawk Weapon Control System (TTWCS), originally tested on the Floating Shock Platform (FSP) with a 14-Hz deck simulator;
- A sphere array beamformer processor (SABP) engineering design model (EDM) with internal isolation.

The successful completion of these tests (see references 2 through 5) attests to the Chirp Shock Test Machine's versatility and repeatability in numerous program applications. Test results confirm that performing a shock test using the Chirp Shock Test Machine enables the detection of equipment deficiencies during (rather than after) the test series and allows the incorporation and test(s) of any necessary modification(s), saving both time and money.

This document describes the Chirp Shock Test Machine to demonstrate that this shock test tool has the potential to enhance the Navy's current shock-test program and augment the operational effectiveness of the Fleet while at the same time realizing significant savings in personnel and equipment costs for shock testing and verification.

2. SHOCK TESTING METHODS

2.1 BACKGROUND

2.1.1 Department of Defense Directive (DODD) 5000.1

In May 2003, the Department of Defense (DOD) issued a directive (reference 6) requiring that as much commercial off-the-shelf (COTS) equipment—in lieu of militarized equipment—as possible be used in all Command, Control, Communications, and Intelligence (C^3I) systems for all submarine platforms. While affording reduced acquisition costs and more expeditious Fleet introduction of progressive hardware and system upgrades, the use of COTS equipment poses some unprecedented challenges to the Navy, including the need for increased shock testing since COTS equipment is less hardened than militarized equipment.

2.1.2 Military Specification 901D Interim Change #1

In 1994, military specification MIL-S-901D, "Shock Tests, H.I. (High-Impact) Shipboard Machinery, Equipment, and Systems, Requirements for," was amended by Interim Change #1 (reference 7) (hereinafter referred to as "MIL-S-901D I.C. #1"), which, among other changes, broadened the scope of the specification. The following paragraph was added to address the qualification of low-frequency components:

> For equipment known to have at least one natural frequency below ten (10) Hertz, qualification described in this specification may not fully or conservatively represent [the] shipboard environment. If the equipment on its foundation has natural frequencies below ten (10) Hertz, especially if it is sensitive to large displacements, consideration shall be given to additional evaluation, analysis or alternate testing to assure suitability of the equipment for shipboard service. Such additional evaluation, analysis, or alternate testing shall be performed only when specified in the contract documents.

Additional evaluation, analysis, or—most extensively—alternate testing can increase the cost of conducting shock testing and attaining shock qualification of components with naturally low frequencies.

Also added to MIL-S-901D I.C. #1 was the shock test criterion of a 90° test during Medium Weight Shock Machine (MWSM) testing of submarine-installed equipment. The basis for this addition is the need to replicate the athwartship input, as well as the vertical input, during medium-weight shock testing.

2.2 TRADITIONAL SHOCK TESTING

Verification of the performance capabilities and reliability of COTS equipment is paramount in its introduction into submarine platforms that formerly were outfitted with only rugged, militarized equipment. The need for shock isolation in the installation of COTS equipment has been acknowledged. With the exception of the *Virginia*-class submarine, which incorporates isolation on a modular-deck level, the current use of COTS equipment necessitates isolation at either the component level or the principal unit level. Reference 7 specifies that the use of shock isolation requires that testing be performed on the FSP (a NAVSEA-approved heavyweight shock test vehicle).

Historically, Navy shock test methods have tried to duplicate damage potential—and not necessarily accurate shock inputs. As a result, the shock test methods specified in reference 7 can lead to some equipment being over-tested and some being under-tested. The increasing use of COTS equipment on U.S. Navy ships and submarines to control costs has led to the need for shock test methods that more effectively capture the actual ship's response characteristics.

Because of its inherent non-hardened design, COTS equipment typically must either be shock-isolated or mounted in a shock-isolated cabinet to pass shock testing. High-fidelity structural modeling of ships, when subjected to real attack scenarios, has led to the realization that current MIL-S-901 I.C.#1 shock test methodologies can result in shock inputs to test articles that do not effectively capture a ship's true environment.

This deficiency is especially applicable to submarines. Current shock test methods for isolated equipment require that the design of the equipment be verified by testing on an FSP, which excites primarily in the vertical direction. The submarine environment differs from surface ships in that shock inputs are equally as likely to be encountered in the athwartship direction (lateral and front-to-back) as in the vertical. Based on the fact that contractors are tasked to pass contractually obligated shock testing, there are current submarine equipment designs in which isolation techniques in only the vertical direction have been employed.

2.3 CHIRP SHOCK TEST MACHINE

2.3.1 Description

The Chirp Shock Test Machine is a hydraulically-driven, computer-controlled shock test machine that uses two displacement tables to test equipment independently in the vertical or horizontal directions. A computer-based controller sends an electrical drive signal to a hydraulic servo-valve that controls fluid flow to hydraulic actuators that drive the respective tables. These cylinders then drive the table motion to reproduce a predetermined time history that is based on either actual shock test data or analysis.

The Chirp Shock Test Machine was designed to simulate the large-displacement, low-frequency environments encountered on shock-isolated components/systems when exposed to underwater explosions. The criteria used to match the shock environment have been defined by meeting the velocity-time history and shock response spectra (SRS) computed with 5% and 25% damping coefficients.

2.3.2 Upgrades

In 2004, several improvements were made to the hydraulic system of the Chirp Machine. These changes doubled the energy storage capacity of the accumulators and provided a closed-oil system to prevent contamination from air and/or particulates. The table actuator size was reduced to increase velocities; remote oil bleeds were added to remove entrapped air; and the oil return lines were modified to reduce unwanted back pressure. These changes have enhanced the Chirp Shock Test Machine's performance in that the maximum velocity now exceeds 11.5 ft/sec, as shown on table 1. Additionally, only one machine operator is now required, instead of the minimum of two previously required.

Table 1. Chirp Shock Test Machine Velocity Ranges

Test Item Weight (pounds)	Measured Peak Velocity (ft/sec)
400	11.6
1000	11.4
3000	11.2

Figure 1 shows the horizontal table of the Chirp Shock Test Machine that was used to test an electronic data module cabinet for lateral shock.

Figure 1. Chirp Machine Configured for Horizontal Testing

Figure 2 displays a time history of past and present velocities from the Chirp Machine, using the same programmed input file. Note that greater shock testing capability was realized as a result of the improvements to the hydraulic system: velocity performance was increased from 7.0 ft/sec to 11.4 ft/sec.

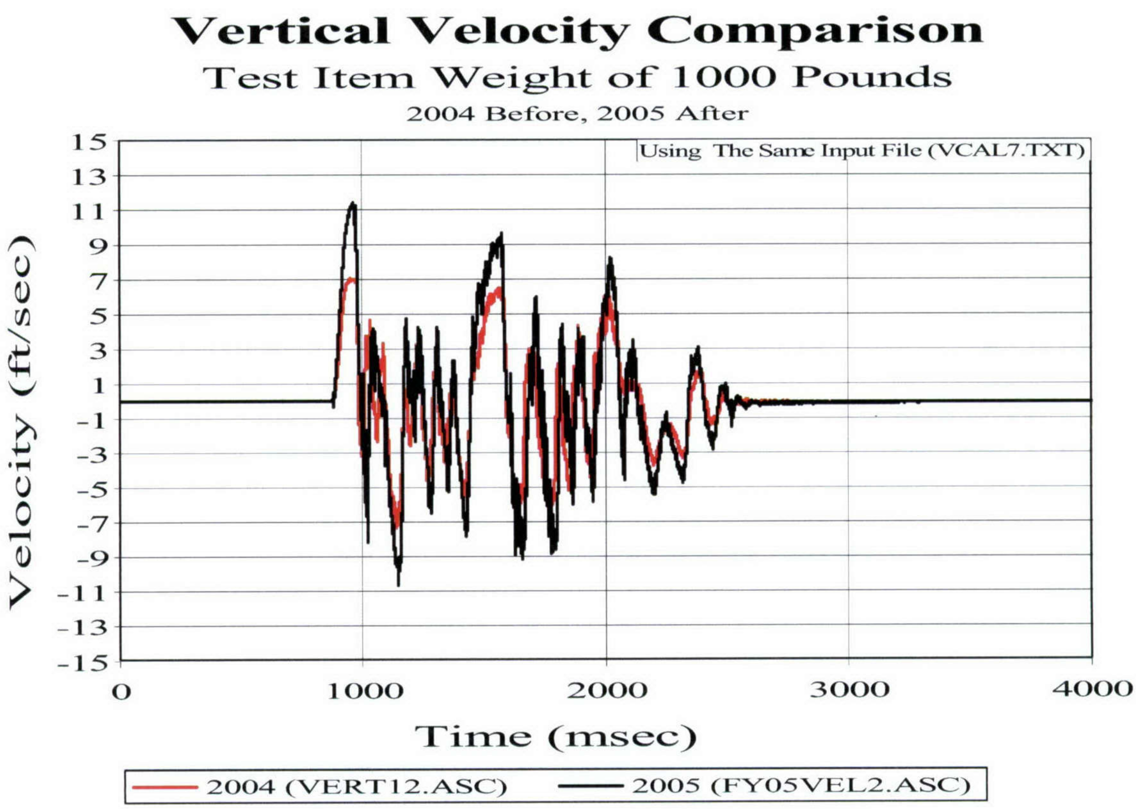

Figure 2. Data Indicating Chirp Performance Increase

3. CHIRP SHOCK TEST RESULTS AND ASSESSMENT

3.1 CHIRP TESTS

The Chirp Shock Test Machine is a capable shock testing device for a wide variety of cabinets and components in a multitude of programs and applications. It is the only Navy laboratory-based machine capable of performing controlled, low-frequency, large-displacement testing that is required for shock-isolated equipment/components or equipment to be installed on isolated decks.

This section provides examples that demonstrate the capabilities of the Chirp Shock Test Machine. It also presents the results of tests during which a series of Chirp Machine input functions, derived directly from the FSP or from shock analysis provided to NUWC Division Newport, was replicated. A comparison of the outputs underscores the similarity in shape and magnitude of the data, confirming that the Chirp Machine is capable of reproducing certain specific shock environments for components/cabinets mounted to isolated platforms/decks.

3.1.1 Defined Environment Testing

The "defined environment" is a concept that has been developed from a recognized need for more accurate shock testing of shipboard equipment that is more representative of the actual environment. The defined environment concept accurately describes the shipboard environment at the installation location of the particular equipment. Conversely, a worst-case-environment envelope can be identified, encompassing a range of equipment locations. In this case, the location for a particular piece of equipment—after successful completion of the prescribed shock testing—could be unrestricted and preclude the need for any additional shock testing.

The environment is defined through the use of high-fidelity models of the ship, using selected attack scenarios as the inputs to the model. The implementation of modern analysis tools and techniques has resulted in accurate predictions of the ship shock response to potential attack scenarios. The resulting analytically derived response at the chosen location provides the input to the equipment mounted to that particular structure.

Additionally, and perhaps most important, the testing conducted using the FSP for both surface ships and submarines is essentially the same: there is little, if any, differentiation in the test standard, despite the fact that surface ships and submarines are two significantly different types of naval vessels. When the predicted analytical modes that the Chirp Machine can realistically replicate are evaluated, it is evident that the athwartship input (as well as the vertical) is an integral attribute of the Chirp Shock Test Machine. The current FSP test environment is primarily vertical because the FSP was designed for the conduct of surface-ship shock testing. Attempts were made to correct this shortcoming by the initiation (in MIL-S-901D I.C. #1) of a 90° test for submarines using the MWSM. In cases where shock isolation is used in the design, however, MIL-S-901D I.C. #1 specifies an FSP shock test.

The ability to program the Chirp Shock Test Machine, using time-history shock results from previous testing or analysis (fine-tuned where necessary), and then generate the desired specific shock responses for equipment being tested can much more accurately represent the actual equipment shock environments.

3.1.2 IEEE Prototype/SABP1 Cabinets

During September 2002 and June 2003, two series of tests were conducted on cabinets supplied by Lockheed Martin Corporation (LMCO) using the Chirp Shock Test Machine. These tests were conducted as a means of shock qualifying by extension seven cabinets (two Grade A and five Grade B) for shipboard installation. Composite curves that enveloped the deck responses for seven individual locations and selected attack scenarios were used as the shock-loading inputs.

3.1.2.1 Initial Chirp Test of the IEEE Prototype and SABP1 EDM Cabinets. During the initial series, two cabinets were subjected to shock testing using the Chirp Shock Test Machine:

- The dummy-weighted SABP1 EDM Cabinet (designated the "IEEE Prototype"), which featured a single-degree-of-freedom internal-isolation system that provided shock mitigation to the electronics enclosure in the vertical axis.
- The SABP1 EDM, which contained the same isolation system as that of the IEEE Prototype and the Grade A electronics only (dummy weights were added to simulate the remaining non-Grade A electronic components).

The purpose of the test was twofold: (1) to initially calibrate the vertical and horizontal tables of the Chirp Machine and (2) to verify the operation of the internal shock-isolation system prior to committing to a final design. The analytical inputs that were used during the test were supplied by Northrup Grumman Newport News Shipyard.

The testing of the IEEE Prototype Cabinet served as the initial calibration of the Chirp Machine's vertical and horizontal tables. Post-test inspections of the IEEE Cabinet, after testing on the horizontal table, revealed that the dummy-weighted prototype had incurred extreme structural failures. The bolted connection between the sides of the cabinet and the bottom, which is rigidly bolted to the deck, failed, as did the front and rear cover screws on the cabinet.

The testing of the SAPB1 EDM was then conducted. After testing on the vertical table, inspections revealed three internal failures, all of which compromised Grade A operability: (1) the power breaker tripped, which interrupted power to the ship safety/self-protect chassis; (2) the mounting flange on the power supply bent, and a mounting fastener failed; and (3) a Raceway Interlock card, with no integral mechanical retention, unplugged.

The SAPB1 EDM and dummy-weighted IEEE Prototype Cabinets were subsequently returned to LMCO for design modifications and rework.

3.1.2.2 Second Chirp Test of IEEE Prototype and SABP1 EDM Cabinets. The IEEE Prototype and SABP1 EDM Cabinets were returned to NUWC Division Newport in June 2003 after the design modifications were incorporated. The modifications comprised reinforcement of the cabinet (to prevent structural failures) and the addition of shock-certified circuit breakers, mechanical retention for the circuit cards, and a stronger power-supply mounting bracket.

The IEEE Prototype was again used to calibrate the vertical and horizontal tables of the Chirp Shock Test Machine. The IEEE dynamically simulated the SABP1 EDM, which facilitated calibration of the tables as well.

Post-test inspections of the SABP1 EDM Cabinet revealed the following errors:

1. A shorting plug, which was found to have been improperly secured, was unplugged; it was subsequently secured properly, thus preventing a recurrence.

2. One of the Grade A breakers tripped, attributable to loose mounting screws on the breaker panel. The mounting screws were tightened, thus preventing a recurrence.

3. Performance-monitoring and software task errors were generated, and Grade A operating functions shut down several times, necessitating rebooting of the software to restore operation. (Discussions with the vendor ensued in an effort to incorporate software changes that would enable automatic recovery of the system.)

The results of these tests were submitted to both NAVSEA 05P3 and the Program Manager for resolution. A request was submitted for shock qualification by extension of all seven cabinets.

These two test series are documented in reference 2. The ability of the Chirp Shock Test Machine to reproduce composite inputs, which—in a single test—enveloped several attack scenarios and multiple shipboard conditions, was demonstrated. The test series also underscored the potential of Chirp in exposing design weaknesses and structural deficiencies. These tests culminated in equipment whose form, fit, and function were significantly enhanced for shipboard application and are, in fact, currently installed on submarine platforms.

3.1.3 TTWCS Tomahawk Equipment Cabinet (TEC) Rose Video Switch Testing

In 2003, the TTWCS TEC AN/SYK-28(V) was subjected to a series of explosive shock tests on the FSP 14-Hz deck in accordance with reference 7. The TEC was subsequently redesigned. Because the original Rose Video Switch was no longer available (because of obsolescence) and the new switch design deviated significantly from that of the original, a retest was required. The cost of the switch was negligible compared to the cost of repeating the FSP test (50 times greater); consequently, because of budgetary and schedule constraints, NAVSEA 05P3 approved using the Chirp Shock Test Machine to fulfill the shock-test requirement at the component level.

The original FSP test incorporated instrumentation that recorded shock data in the vicinity of the Rose Switch. A set of acceleration-time histories for the vertical, side-side, and front-back directions (all of which were derived from the FSP test) was furnished to NUWC Division Newport for Chirp Shock Test Machine testing. SRS calculated from the original data were compared with SRSs calculated from data obtained using Chirp inputs. Figure 3 compares the vertical shock response of the TEC obtained above the mount on the FSP with that obtained in the test using the Chirp Shock Test Machine.

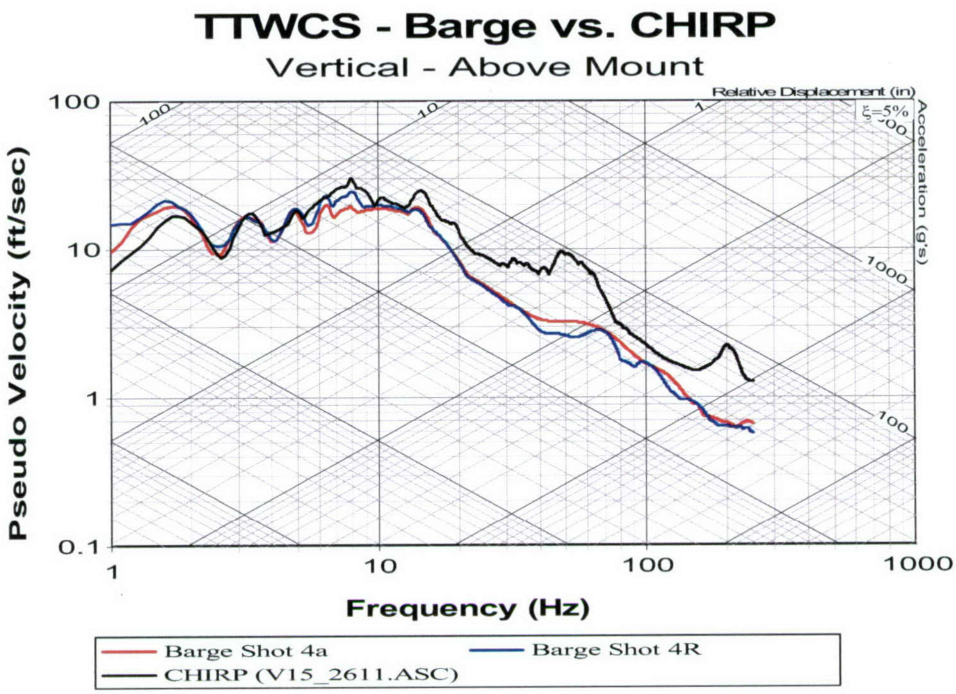

Figure 3. Vertical Shock Response Comparison for the TTWCS TEC Testing

A review of the data indicates that the Chirp Shock Test Machine was able to reproduce and, in some cases, exceed the frequency content of the FSP input (from 2 to 250 Hz) to the Rose Switch. The fact that the input file used in the time domain had the same duration as that of the original barge test indicates that the Chirp Machine input file was an accurate simulation of the time history measured on the FSP.

At the conclusion of the test series, the complete data package was forwarded for review to NAVSEA 05P3 and the Underwater Explosion Research Division, both of whom concurred that the Chirp Shock Test Machine test data were sufficient and acceptable and that additional FSP testing would not be required. A shock-qualification-approval letter for the Rose Video Switch was generated by NAVSEA. A comprehensive report documenting this component-level test is contained in reference 3.

3.1.4 TTWCS TEC

The TTWCS TEC was initially shock-tested using the FSP with the 14-Hz deck. Subsequent modifications to the TEC (Engineering Change Proposals (ECPs) 3242 and 3272) required that additional shock verification be conducted. Because of budgetary and schedule constraints, alternatives to the Navy's FSP test were investigated; NAVSEA 05P3 approved the use of the Chirp Shock Test Machine. ECP 3242 modified the TTWCS TEC by including A6, A8, A9, and A10 Chassis. Reference 4 documents the shock test of those components at the system level in all three directions (vertical, front-back, and side-side) using the Chirp Machine.

ECP 3272 identified the modification of the A10 Chassis, resulting in another test series using the Chirp Shock Test Machine (see reference 5). Dummy weights that simulated the TEC Chassis and test fixture were mounted to the Chirp Machine and calibration shots were performed. The resultant data were forwarded to NAVSEA 05P3 and the Naval Surface Warfare Center Carderock Division (NSWCCD) for review. It was verified that the Chirp Machine did, in fact, replicate the FSP test environment. The A10 Chassis test-fixture assembly was then mounted to the Chirp Machine. Inputs that had been derived from the instrumentation used during the previous FSP testing (three triaxial sets of accelerometers (nine total)) were used to form the combined-data criteria that were provided by NSWCCD.

Figure 4 plots the NSWCCD-provided SRS criteria for 5% and 25% damping coefficients for the side-side test direction (heavily bolded lines) and the calculated Chirp SRS, which enveloped these criteria. Figures 5 and 6 contain the same parameter data for the front-back and vertical test directions, respectively. In all cases, it is apparent that the Chirp Shock Test Machine was capable of producing results very similar to those derived from testing using the FSP.

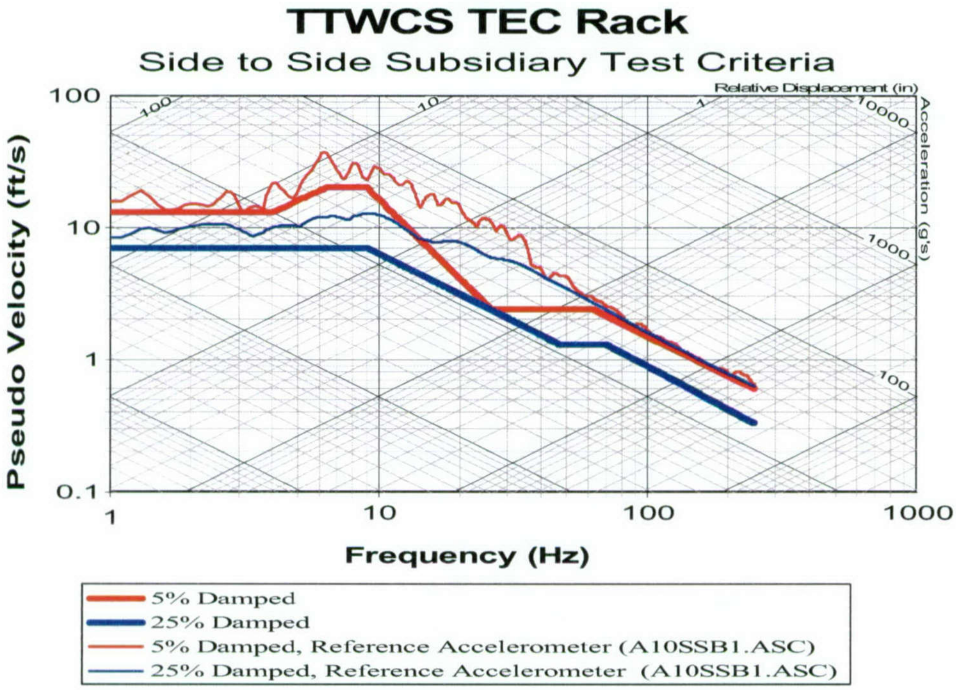

Figure 4. Side-Side Data Derived from TTWCS TEC Testing

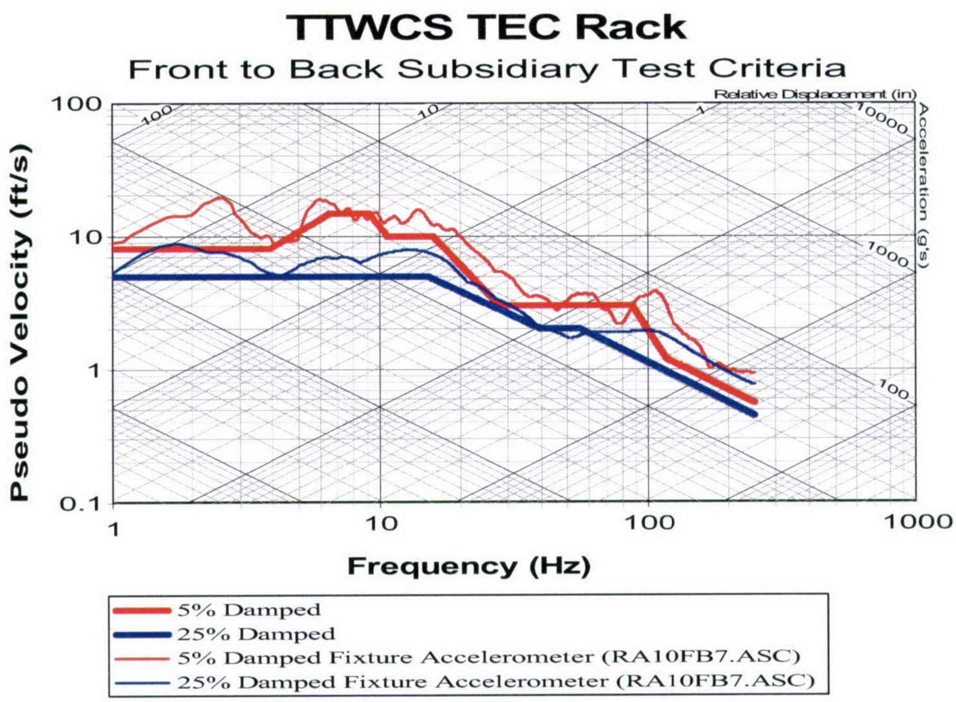

Figure 5. Front-Back Data Derived from TTWCS TEC Testing

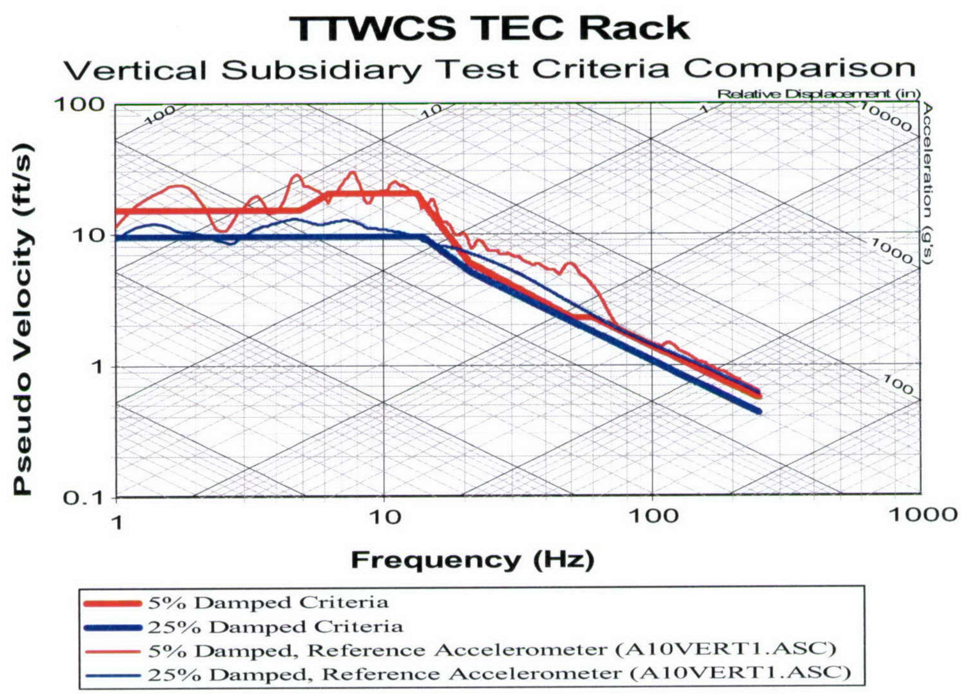

Figure 6. Vertical Data Derived from TTWCS TEC Testing

3.2 CHIRP MACHINE ASSESSMENT

3.2.1 Repeatability of Chirp Data

Data derived from shock testing using the Chirp Shock Test Machine have demonstrated the Machine's high degree of repeatability. Figures 7 and 8 display repeatability characterization data that were acquired during testing on the Chirp with a 1000-pound mass mounted on the horizontal table, using an input file obtained from an FSP above-mount environment.

In figure 7, the velocity-time-history repeatability plot data were captured by the linear variable transformer, which was mounted adjacent to the table actuator. Data for the SRS repeatability were calculated from a reference accelerometer that was mounted on the base of the table. The SRSs shown in figure 8, which are computed from the time histories in figure 7, also attest to the high degree of repeatability of the Chirp Shock Test Machine.

The same control system is used to operate the vertical table and the horizontal table; consequently, the same degree of control is achieved on both tables, and the repeatability characteristics of the tables are very similar.

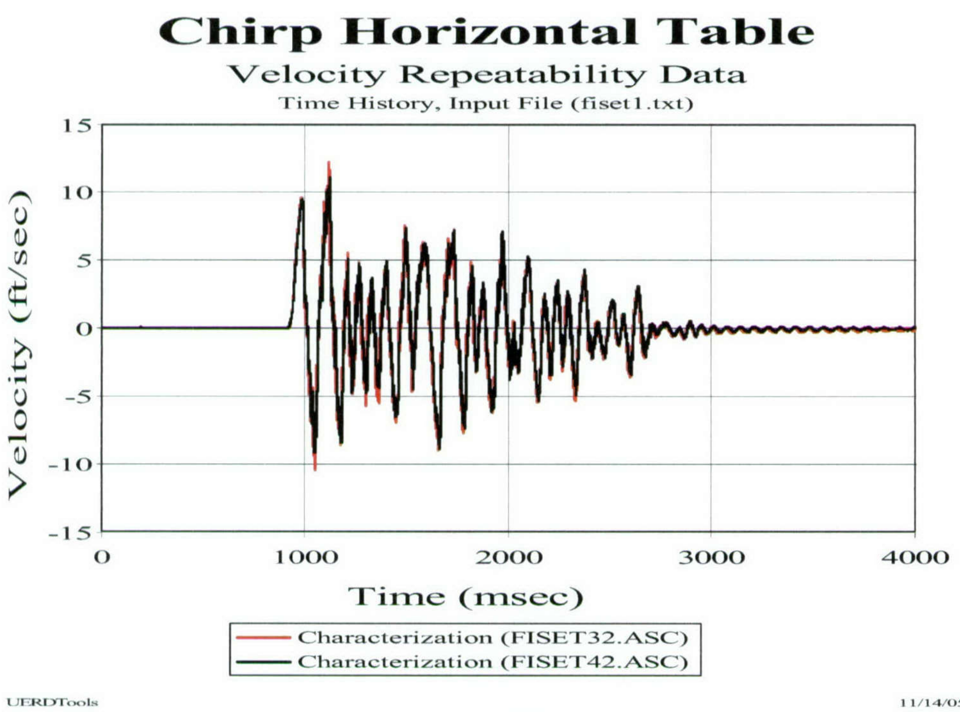

Figure 7. Example of Velocity-Time History Repeatability

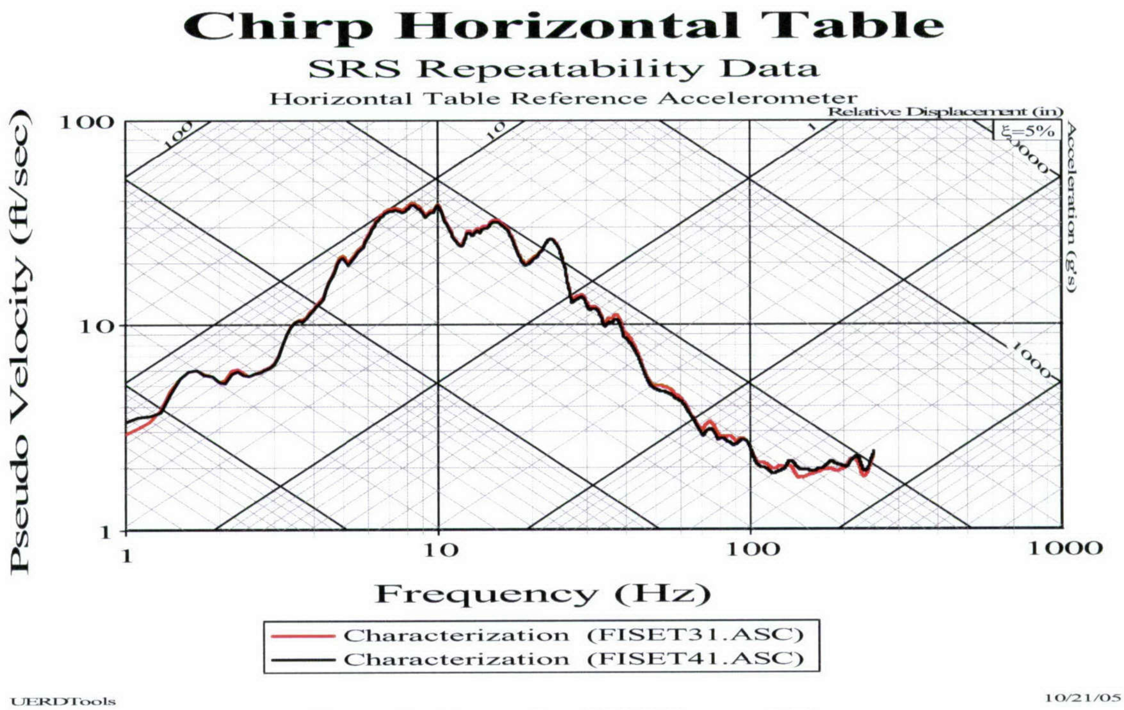

Figure 8. Example of SRS Repeatability

3.2.2 Comparison of Chirp Responses and Requested Test Inputs

In 2005, NAVSEA 05P3 requested that NUWC Division Newport conduct testing on the Chirp Shock Test Machine, using a sampling of shock test input curves that represented several isolated-equipment environments. Figure 9 illustrates a sample test result from the characterization work performed to determine the Chirp Machine's operating envelope. (When all tests have been completed, all test results will be forwarded to NAVSEA 05P3.)

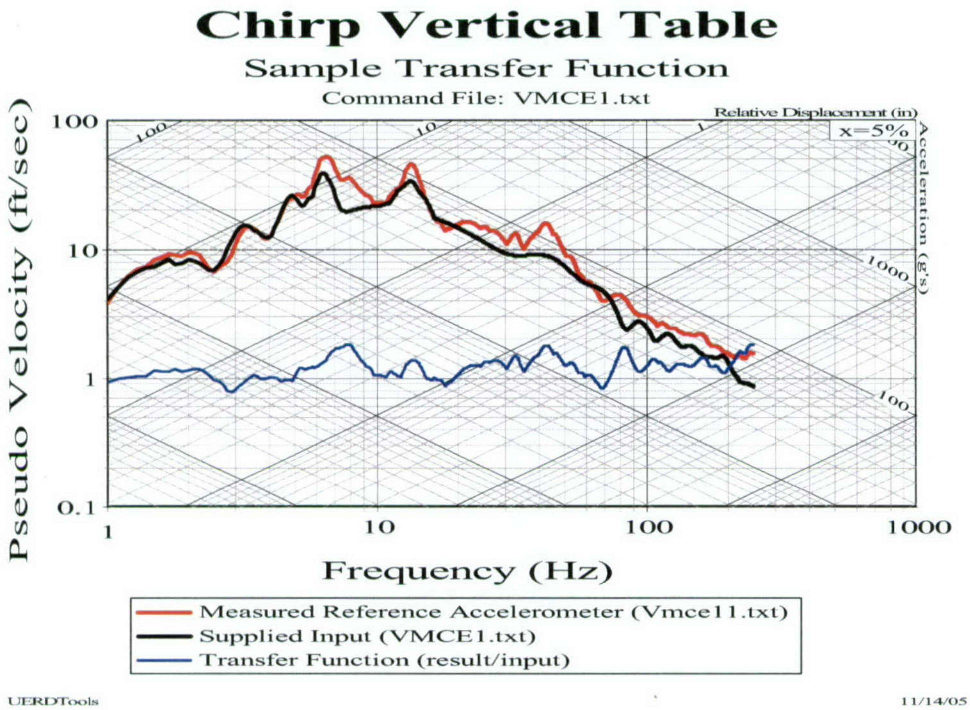

Figure 9. Comparison of Chirp Test Inputs and Requested Inputs

The sample data shown in figure 9 reflect the capability of the Chirp Shock Test Machine to replicate—without alteration—a given input. The transfer function, denoted by the blue line, is a measurement of the precision of the Chirp Machine's response to the supplied input. If the response of the Chirp Machine were perfect across the operating frequency range, the transfer function would appear as a constant value of 1. The peaks above the horizontal line indicate instances where the magnitude of shock was greater than that required. The data illustrated in figure 9 compare the sample input, as requested by NAVSEA 05P3, and the resultant Chirp inputs (intended to duplicate the target curves). The correlation between the Chirp Shock Test Machine test inputs and the given inputs is considerable; additionally, no alteration of the supplied input occurred.

3.2.3 Accuracy of Chirp Testing

The aforementioned tests, which document the proven ability of the Chirp Shock Test Machine to accurately reproduce specific shock-test inputs, demonstrate that the Chirp Machine is an ideal platform for defined environment testing. The examples cited clearly illustrate that defined shock-test inputs can be reproduced—without resultant alteration—by and through utilization of the Chirp Machine.

4. USING THE CHIRP SHOCK TEST MACHINE

4.1 PROPOSED APPLICATIONS

4.1.1 Development Phase

During the development phase of components and/or systems, the Chirp Shock Test Machine could be used to realize significant savings in time and expense. Development phases of components/systems subject to the requirements of reference 7 delay the performance of shock testing until the completion of design and fabrication—at which time testing is conducted using the FSP. Results frequently identify inadequacies in the equipment design that are sometimes resolved by a modification(s). Because of the high cost of an FSP test, these modifications may never be retested.

The time and expense invested in the development phase of a component/system can be minimized if, during the development phase, the performance of that equipment could be validated by inexpensive shock testing utilizing the Chirp Shock Test Machine. Savings would be realized in engineering and production costs, and the equipment's reliability would be enhanced if development testing were employed early in the procurement cycle and on a greater scale. The ambiguity in the delayed performance assessment of a shock-isolated component/system that is FSP-tested at the conclusion of the development phase could be eradicated.

4.1.2 Component Test/Retest

The Chirp Shock Test Machine—instead of the time- and cost-excessive FSP—can also be utilized in the test of COTS components, principal units, or cabinets that are shock-isolated. Quite often, when an FSP shock test of a component/system results in failure(s), the equipment is re-engineered, but it is never retested (repeat FSP testing is virtually unrealistic when program schedule and cost restraints are considered). The disproportionate time and expense associated with testing/retesting low-cost components (including COTS) have led to the use of analytical means, as well as extensions and waivers, for obtaining shock approval. An approved low-cost testing alternative to verify the acceptability of redesigned equipment or components, such as the Chirp Shock Test Machine, is preferable to verification by analysis (the cost associated with a Chirp shock test is similar to that of presently conducted analytical studies).

The conduct of shock testing using the FSP cannot maintain the rapid pace of the evolving COTS equipment/systems installed on Navy vessels. In cases where equipment has been upgraded to incorporate technical improvements, the practice of verification by similarity should be addressed. Determining how many technical upgrades to a previously tested component/system can be made before the unit is considered to be an entirely different unit and, therefore, necessitates shock testing is an issue that warrants attention. Generally, budgetary considerations are the deciding factors.

It is strongly believed that the overall reliability of ship and submarine components and systems can only be truly verified by physically testing them in a wartime shock environment. The Chirp Shock Test Machine provides a viable alternate test vehicle to achieve this verification. An increase in component/system shock retest would further serve to augment the operational effectiveness of the Fleet.

4.2 CHIRP MACHINE APPROVAL PROCESS

Even though the Chirp Shock Test Machine is a versatile, effective shock test tool, no clearly defined process presently exists to use Chirp as an alternative to the FSP test. Because of the fiscal climate and ever-increasing use of COTS equipment, it is more critical than ever to establish a streamlined process to obtain approval for the Chirp Shock Test Machine to be used as an alternative shock test vehicle. Such a process is proposed in reference 8.

5. CONCLUSIONS AND RECOMMENDATIONS

The initial associated cost of conducting an underwater-explosion shock test series using the FSP is high—especially when compared to the procurement cost of many of the COTS components to be tested—and escalates when retesting is required. Shock testing using the FSP cannot keep up with the rapid pace of evolving COTS equipment/systems installed on board Navy vessels; nor can the FSP replicate shock inputs in the athwartship direction. Consequently, despite the Navy's intent and efforts to outfit the Fleet with equipment that has been shock-qualified, numerous components are currently installed that have not been sufficiently shock-tested. In some instances, analytical assessment has had to suffice.

The Chirp Shock Test Machine provides a test environment that is more controlled and flexible and significantly less expensive than an FSP test series (range of magnitude is approximately 20%). Although the operating frequency range parameters of the Chirp Machine were initially designed to impart a 40-g shock spectrum between 3 and 12 Hz, ensuing analytical and development efforts indicated the Chirp Machine is capable of a broader, extended-range application. Chirp's inherently programmable characteristic affords the realization of an infinite number of shock response spectra.

Additionally, the Chirp Shock Test Machine can be used at the onset of system-level and/or component-level equipment development programs to verify the adequacy of the particular design to meet prescribed shock requirements. During the progression of the program, the Chirp Machine can be used to supplement the FSP for shock development certification of the equipment and subsequent retest and certification, if needed. No analysis can model to the detailed level necessary to ensure the operability of COTS equipment after a shock test; nor can any shock-qualification extension (based on the similarity of a replacement/upgraded component) be generated for the cost of conducting a test with the Chirp Shock Test Machine.

The Chirp Shock Test Machine—which is the only Navy laboratory-based machine capable of performing controlled, low-frequency, large-displacement testing that is required for shock-isolated equipment and components or equipment to be installed on isolated decks—can be a viable alternative and supplement to traditional shock testing. In addition to the fact that Chirp testing is performed in a controlled laboratory environment, there are other distinct advantages in using the Chirp Machine, such as ease of instrumentation placement and data acquisition, repeatable test parameters, incremental input increases, and elimination of FSP-related detriments (for example, excessive time and cost factors and weather dependency). Current Chirp testing can be completed for approximately 20% of the cost of an FSP test series.

The Chirp Shock Test Machine cannot replace existing shock test methods in their entirety, but it can be a viable supplement to and, in some cases, alternative to traditional shock testing. If, during the conduct of traditional shock testing, those systems that comprise low-frequency components and/or equipment that have been or will be tested on a 14-Hz deck were strategically instrumented, the Chirp Machine could be used for component-level testing.

The various capabilities and past successes of the Chirp Machine have been outlined in this document, and they are testaments to the machine's accuracy and repeatability characteristics. Recent upgrades significantly expanded the Chirp Machine's shock testing capacities, thereby further increasing its utility.

Shock testing with the Chirp Machine could encompass several specific applications, for example:

- Testing of combat system cabinets such as TTWCS.
- Retesting of failed, redesigned, or upgraded Grade A/B components/systems.

The Chirp Machine could also be utilized for other programs (for example, as part of a LEAN initiative). The benefits to be derived from using the Chirp Shock Test Machine are attainable if approval is obtained from NAVSEA 05P3. That approval process can be facilitated by using the procedure defined in reference 8.

The Chirp Shock Test Machine is an effective shock test tool, with numerous intrinsic applications—especially with regard to the increased emphasis on COTS equipment for shipboard installation. MIL-S-901D I.C. #1 does not provide adequate guidance for cost-effective alternative tests, which should be better defined. The Chirp Shock Test Machine is a Navy asset that is, to date, under-utilized. The implementation of the Chirp Machine is ideally suited to clarify the "alternate testing" method by which low-frequency components can be qualified. The Chirp Machine is capable of reproducing the isolated shipboard shock environment, as determined by analysis or measured from tests in the field, while also enabling the shock test platform to be specifically tailored for individual equipment with multiple shipboard locations.

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